HISTORY OF BIPED ROBOTS. PROBLEMS. SOLUTIONS

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Abstract: This paper presents the history of biped robots creating from ancient time to today. The fist devices simulated human and animal motions, but had no "sense organs". Today many modern interesting walking devices are created. The main problem in this field is modeling and dynamic control.

Keywords: walking robot, history of biped robots, movement control, dynamic stability

Introduction

Walking robots are the most wanted, important and interesting ones and their stability is the most crucial problem these days. Two main types of bipedal walking are present in the literature: static and dynamic [1]. The static walking is always stable, but such robots have low speed and big weight [2]. Dynamic walking is considered to be human like. As opposed static, dynamic robots are faster, more maneuverable and dexterous. The feet of such robot are very small, like dots, so it is impossible to be stable for them. Dynamic walking means to constantly fall, but to bring forward the swing leg in time to prevent tilting over. The control system must provide stability of walking and its efficiency [6],[21]. So it is the main problem at creation of the modern walking robots.

Researches of dynamic walking are connected with names of P. L. Chebyshev (1824-1894), I.I. Artobolevsky (1905-1977), A.E. Kobrinsky (1915-1992), Yu. I. Neimark (1920-2011), D.E. Okhotsimsky (1921-2005), Yu.V. Bolotin (1926-2008), V. V. Beletsky (1930-), M. Yukobratovich (1931-), E.A. Devyanin (1931-2002), A. K. Platonov (1931-), A.M. Formalsky (1938-), etc. The first walking robots were used for entertainment. More advanced walking robots were developed with the various branches of technology and science [7]. They turned into devices and mechanisms which could exempt people from a hazardous to health work, in the conditions of the raised radiation, high or low temperature, in hard-to-reach areas, and also for rehabilitation of people with the limited possibilities [14].

1 The fist walking robots

The robot is the Czech word. In 1921 Czech writer Karl Capek introduce the play "R.U.R" Rossum's Universal Robots, where the androids revolted against people. These human-like machines are called Robots based on the Czech work robota meaning labor [17]. In 1495 Leonardo da Vinci performed the first the detailed project of walking robot, it was able to move hands and turn the head (Figure 1).

Figure 1. Mechanical knight of Leonardo da Vinci

The French mechanic Jacques de Vocanson in 1738 built the androids which made him the world famous. The robot-flutist was tall like the adult and was able to hold a flute at lips. Blowing and pressing flute valves, the machine played 11 various melodies. Another the most known invention of Vocanson is the Mechanical duck (Figure 2).

Figure 2. Mechanical duck of Jacques de Vocanson

It consisted of 1000 details. The duck was covered with the real feathers, was able to walk, move wings, grunt, drink water, peck grain and, after milling it inside, crap on a floor [9]. In 1865 Johnny Breinerd built the Steam Man (Figure 3).
Breinerd’s mechanism was three-meter high, it easy for it to pull a cart with five passengers. Instead of a hat, the Steam Man had a flue pipe with the black smoke. The Steam Man was able to move with a speed up to 30 miles an hour.

All mentioned inventions were interesting, but these devices had no mechanisms which could inform them where and when it was necessary to put a foot [15].

After discovery of uranium in 1896 and its harmful effects on an organism it became necessary to create the robots which could replace people during work with radioactive materials. So it was necessary to solve one of the most difficult scientific tasks – how to control the walking robot.

2 The development of robotics

In 1878 the Russian mathematician Chebyshev presented a model for a locomotion system at the World Fair in Paris (Figure 4).

Chebyshev's mechanism was the first walking machine and survived as a landmark in locomotion research.

During the period from 1900 to 1940 not so many walking mechanisms were invented because of the Russo-Japanese War and the World War I. The most interesting of them was a robot which lectured at the «Century of Progress» exhibition in Chicago in 1933. Its breast and stomach were transparent and robot showed a gullet, a stomach, intestines and a liver and explained a structure of internals. The first Russian robot android B2M was created in 1936 by the schooler Vadim Matskevich and in 1937 he was awarded the diploma of the World Fair in Paris. In 1939 at the World Fair in New York «Westinghouse Electric Corp» presented the mechanical humanoid robot «Elektro» and the robot-dog «Sparko». Elektro was 136 kg, was able to walk, talk and smoke.

In the 1960th computer technologies and facilities began to develop so it became possible to create the controlled walking robots [16]. Also in that period the medicine actively developed and in the USSR, the USA, Yugoslavia, Italy and Germany the special devices for people who were injured were designed. Such devices were called exoskeletons.

In 1963 in Cornell University's (New York) laboratory of aeronautics N. Mayzen developed passive exoskeleton (Figure 5) which registered the movements of all links of a body, except a neck and fingers.

The obtained data represented interest for development of an active exoskeleton, which was able to support at least a portion of the load of a user's body.

In 1966 Ichiro Kato from the Waseda University in Tokyo, started his work on biped robots. His first robot WL-1 is shown in Figure 6.

In 1969 WL-3 from 1969 performed static walking. In 1970 WABOT-1 was built, it accepted as the first fully articulated anthropomorphic biped. The top part and center of gravity of robot's body moved to the left and to the right due to the hinges. The program control of walking was applied in this robot. The walking was considered to consist of some consecutive movements [19]. The program of walking was stored in the block of memory and could be changed. Process of walking was synchronized by the impulses given in certain intervals of time. Each hinge was equipped with the potentiometer which signals served as feedback. Robot turned by manual switch. Its speed was slow and the walking was static.

In the 1970th M. Vukobratovich and the institute of automatic equipment and telecommunications of M. Pupin in...
Belgrade worked on creation of the biped device—the active exoskeleton. It consisted of a metal framework, its links and hinges were like the bones and joints of the person [18]. Exoskeleton was equipped with pneumatic actuators, substituting of muscles, and system of the sensors signaling about position of joints. It was put on the person. The device was supplied with the portable program device providing the stable anthropomorphous walking [4], [10]. Developers investigated biomechanical and physiological properties of movements. Synthesis of anthropomorphous walking was the original. Some coordinates was set like a nominal law of the movement, and values of the remained coordinates were calculated from the dynamic links. The three-level control system was created for this robot. Ideas of the Soviet physiologist prof. N. A. Bernstein made a great impact on formation of such approach to biped control.

3 Robots today
There are not so many modern devices deserving attention today. For example «Walking assist device» by Honda (Figure 7).

![Figure 7. Walking assist device by Honda](image)

Walking assist device is an exoskeleton, it is intended, as a rule, for increase human efforts. Walking assist device can be used for making hard work, such as loading in places difficult of approach for wheel transport [8], for repair work, rescue operations. Besides, exoskeleton can serve for rehabilitation of the injured people.

It is necessary to mention the walking chair WL-16 by the Waseda (Figure 8).

![Figure 8. The walking chair WL-16](image)

The walking chair WL-16 was created as the alternative to wheel chair which is not adapted for walking up and down the stairs. Mechanisms of feet have 6DOF.

Due to the parallel connections of drives the walking chair has high mechanical rigidity and precision of movements that increases its loading capacity and the speed of movement [12].

4 The control problem of bipedal robots
There are many modeling and control problems but we will mainly focus on a stabilization of the biped walking in the field of specified movement. In general, a bipedal locomotion system consists of several members that are interconnected with actuated joints. Its point of support changes discretely [11], [13]. The parameters of control are the time of the beginning of the next step and coordinates of a reference point [3]. So to stabilize walking it is necessary to define «when and where to put a foot».

Feedback is based on the equations of the ideal mechanism - the turned pendulum [20]. The analysis of its movement allows to solve a problem "when and where to put a foot". In this case this problem has solution set. For modeling a control system it is necessary to work out the nonlinear differential equations, let initial conditions are equal to final conditions from the previous step [2]. The Figure 9 shows the structure of the biped and coordinates used to describe the configuration of the system.

![Figure 9. Kinematic model of a biped robot](image)

This paper proposes the method of bipedal horizontal walking control of flat machine by defining $T$ - the time of the end of the current step, when $z_{\text{max}}(T) = z_i$, $i$-step number, and place of touchdown at the beginning of the next step. The changing the length of the leg provides horizontal movement of the device [5]. Error $\psi_l$ in emplacement is defined as a difference between point coordinate at vertical position of the leg $Z_{\text{Oi}}$ and its program value $Z_{\text{pr}}$ in the same point of time.

$$\psi_l = Z_{\text{Oi}} - Z_{\text{pr}}$$ (1)

Let the error $\psi$ accepts very big negative values and maximum parameter of a step $z_{\text{max}}$ are defined by design, then the nonlinear function of control is equal to zero when the error is absent, and the nonlinear function is equal to admissible value when the error is maximum. For example $z_1$ is in range from $z_{\text{max}}/4$ to $z_{\text{max}}/2$. Coordinates of the center of gravity at the beginning of the step can be represented as

$$z_i = \frac{z_{\text{max}}}{2} \left[ \frac{1}{2} \arctg(\psi_l \cdot k_2 + \psi_l \cdot k_4) \right] \pi$$ (2)

where $k_2$ and $k_4$ – coefficients of feedback by error and its speed, "" – time derivative. Define speed $\dot{z}_i$

$$\dot{z}_i^2 - k^2 \dot{z}_i^2 = \dot{z}_i^2 \dot{z}_i - k^2 \dot{z}_i \dot{z}_i$$ (3)

where $k = \sqrt{g/L}$; L – height of center of gravity; $g$ – the acceleration of free fall. Define the coordinates of center of gravity of the next step as:
\[ z_{i+1} = \frac{1}{k} \left( \frac{1}{2} + \frac{\text{arctg} \left( \frac{\psi_i, k_p + \psi_i, k_d}{\pi} \right)}{2} \right) \] (4)

From this point of view when the device approach closer to the purpose \( z_i \) decreases from \( z_{max}/2 \) to \( z_{max}/4 \), and \( z_{i+1} \) from zero to \( -z_i/2k \).

Let \( k_p = 2.5 \) m/s, \( k_d = 2 \) s/m. The Figure 10 and Figure 11 present the results of the numerical solutions of the equations (1) - (4).

![Figure 10. Simulated response of the accelerated walking](image)

![Figure 11. Temporary dependence of the accelerated walking](image)

5 Conclusions

(1) From aforesaid it is clear that dynamic biped walking device must be equipped with sensors of absolute linear and angular coordinates, and also sensors of position of kinematic links.

(2) The control system has the hierarchical structure. The lowest level of control is organized like the watching drives and provides desirable position of the device on all possible coordinates. The horizontal coordinates and rotation round the vertical are stabilized at the top level of control according to movement of the device.

(3) In a feedback the element of comparison is the ideal mechanism, it is described by two equations of the turned pendulum for coordinates \( x \) and \( z \) synchronized at the end of the step.

(4) Stabilization of rotation round a vertical is carried out when both feet are on the ground.

References